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Visualisation of fluid flow mechanisms through a viscous-porous rock-analogue medium – experiment and model results

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Understanding fluid flow patterns in the shallow and deep earth is one of the major challenges of modern earth sciences. Fluid flow may be slow and pervasive, or fast and focused. In the deep earth, focused fluid flow may result in, for example, dikes, veins, volcanic diatremes and gas venting systems. In the shallow Earth, focused fluid flow can be found in the form of fluid escape pipes and gas conducting chimneys, mud volcanoes, sand injectites, pockmarks, hydrothermal vent complexes, etc.

Focused fluid flow has been reproduced in visco-plastic models of flow through porous materials. However, the mechanisms that cause fluid flow to focus along such relatively narrow channels, with transiently elevated permeability, have not been investigated thoroughly in experiments. We have carried out experiments in a transparent Hele-Shaw cell. In our experiments, a hydrous fluid is injected into an aggregate of viscous grains, and the mechanisms by which this injected fluid flows are recorded using a digital camera. Our experiments demonstrate a dependence of fluid flow mechanisms on the injection rate. At low injection rate, we observe the formation of a slowly-rising diapir. As this diapir slowly rises through the porous medium, it is fed by transient, focused fluid flow following the path of the rising diapir. Once the diapir escapes through the surface of our aggregate, continued fluid flow through the porous aggregate is focused and transient. At high injection rate, instead of a diapir fed by focused fluid flow, an open channel forms as a result of local fluidization of the granular material.

Our experimental observations are interpreted through visco-plastic models simulating the experimental conditions. These numerical models can reproduce the diapirs observed in our experiments at low flow rate by assuming flow through a layered porous aggregate, with a layer with relatively high bulk viscosity overlying a layer with relatively low bulk viscosity. For low injection rates, such a model reproduces focused fluid flow in the low-viscosity layer, that feeds into a slowly rising diapir in the high-viscosity layer. This model observation thus suggests that the passage of the rising diapir in our experiments leaves a trail, where the aggregate bulk viscosity is lowered and along which ongoing fluid flow can focus transiently.